IX. EETA 79001

Basalt, 7942 grams

Weathering Ae, Fracturing A

Figure IX-1. *Photograph of EETA79001 as it was found on the ice. (NASA # S80-28838)*

Introduction

EETA79001 is the largest stony meteorite returned by the 1979 ANSMET expedition (Cassidy and Rancitelli, 1982). It was found on the ice at the Elephant Moraine location near Reckling Peak, Victoria Land, Antarctica (figure IX-1). This sample is especially important, because glass inclusions in it were found to contain rare-gas and nitrogen isotope compositions matching those of the Martian atmosphere as determined by the Viking spacecraft (Bogard and Johnson, 1983a, Becker and Pepin, 1984, Ott and Begemann, 1985b), hence demonstrating the Martian origin for this class of meteorites (Hunten *et al.,* 1987).

EETA79001 is a unique shergottite (achondrite) containing two different igneous lithologies (labeled A and B) separated by an obvious, linear contact and containing "pockets" and veinlets of dark glass (Reid and Score, 1981). A photograph illustrating the contact appeared on the cover of EOS, January 1981 (figure IX-2), because this is the first meteorite found to contain a "geological contact" between two lithologies. Based on texture, lithology B is a basalt, whereas lithology A is a basaltic melt containing numerous inclusions of mafic minerals as xenocrysts (McSween and Jarosewich, 1983, McSween, 1985).

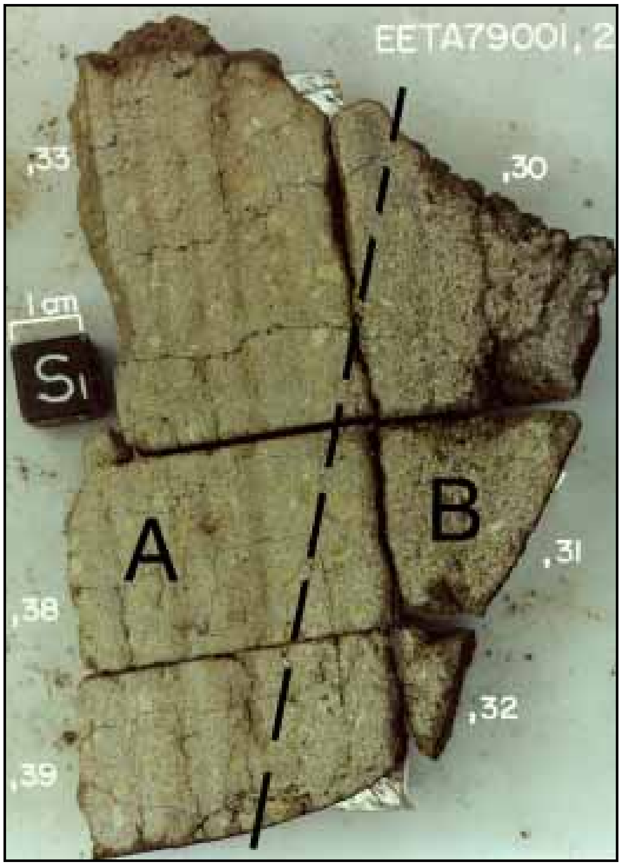

Figure IX-2. Photograph of interior slice showing contact between lithology A and B inside EETA79001. (NASA # S81-25273)

The report of the preliminary examination of EETA79001 (Score and Reid, 1981) makes interesting reading in light of what has since been discovered (see below). *"Several large, black fine-grained clasts as large as 2.5 cm are scattered over the cut face. Some of these black clasts contain vugs which have glass in their interior. Upon chipping one of these clasts, containing a vug, the entire clast popped out easily and no matrix adhered to the clast. Numerous veins of black material criss-cross each other. These veins run through a black clast. The longest vein is ~14 cm long." "The dark clasts are apparently loci of melting; in many cases they connect with the thin black glassy (?) veinlets that traverse much of the meteorite."* These glass veins and black clasts have been loosely referred to as lithology C (see below).

It has proven difficult to determine the original igneous crystallization age of this sample (see section on Radiogenic Isotopes), possibly because it contains a mixture of igneous source rocks and has been disturbed by multiple shock events.

Wadhwa *et al*. (1994) give a model for the origins of the shergottites, including EETA79001 in which *"their parent magmas were ultimately derived from partial melts of the partly depleted mantle of their parent planet, and acquired their distinct characteristics through processes such as crystal fractionation, crystal accumulation, magma mixing/assimilation, and crustal contamination."*

Petrography

All surfaces of this meteorite are covered by at least some fusion crust, so that the sample represents a nearly complete piece. On the top surface, about half of the fusion crust is partially plucked away (figure IX-3). One end (W) has a deep "regmaglypt" that is covered with fusion crust (Score *et al.*, 1982) (figure IX-4). The sample has many penetrating fractures — some lined with thin black glass and connected to interior glass pods. However, the sample was coherent enough to hold together during sawing.

Lithology A is made up of a basaltic host (pyroxene, maskelynite, high-Ti chromite, whitlockite, minor Cl-apatite, ilmenite, pyrrhotite and mesostasis) containing exotic crystals and clusters of olivine, Cr-spinel, and low-Ca pyroxene. Figure IX-5 illustrates the light colored xenocrysts (referred to as lithology X by Treiman, 1995a) in the fine-grained basaltic host (figure IX-6).

Figure IX-3. Photograph of top surface of EETA79001 illustrating partial coating with fusion crust. (NASA # S80-37480)

Mineral Mode

McSween and Jarosewich, 1983						
volume %			,79(A)	,79(B)		
thin section	,75(A)	,68(A)	,80(A)	,80(B)	,71(B)	,69(B)
pigeonite	62.8	60.7	54.5	54.4	32.2	31.8
augite	3.2	6.5	8.5	11.6	23.9	24.5
maskelynite	18.3	15.9	17.0	28.2	29.4	29.6
olivine	10.3	7.2	9.1			
orthopyroxene	3.4	5.7	7.2			
opaque	2.2	4.0	3.0	3.4	3.8	3.4
whitlockite	tr	tr	0.4	0.7	0.2	0.2
mesostasis		tr	0.3	1.1	0.5	0.5

Figure IX-4. *Photograph of west end of EETA79001 illustrating unusual "regmaglypt" and first saw cut. The dotted line is approximate location of the second cut. (NASA # S80-37630)*

Lithology B is a homogeneous basalt containing augite laths in a matrix of pigeonite-augite, maskelynite, ulvöspinel-ilmenite intergrowth, whitlockite, Cl-apatite, and mesostasis (figure IX-7). Mineral compositions indicate an oxidation state similar to that of shergottites. The groundmass of lithology B has a slightly larger grain size (0.3 mm) than lithology A (0.15 mm). Overall, the basaltic texture of lithology B is similar to that of Shergotty (figure IX-8).

The mafic xenocrysts found in lithology A consist of light yellow, olivine/orthopyroxene clusters up to 3 mm in size that are evenly spread out throughout the lithology A. These are referred to as "ultramafic clusters" or "megacrysts" (McSween and Jarosewich, 1983) and "lithology X" (Treiman, 1995a). The compositions of the minerals in these xenocrysts are Mg-rich and are similar to the corresponding phases in the poikilitic areas of ALHA77005 (Wadhwa *et al.*,

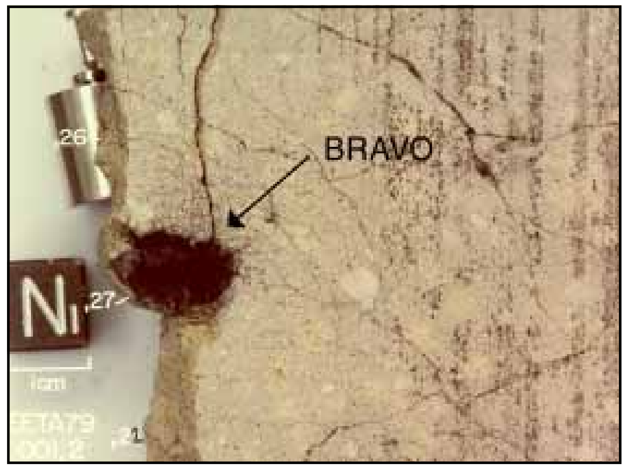

Figure IX-5. *Close-up photograph of a portion of slab EETA79001,22 illustrating "discovery" pod (,27) of glass and fine glass veins in lithology A. Note the very large vesicle in the glass pod (BRAVO). Cube is 1 cm for scale. (NASA # S81-25242)*

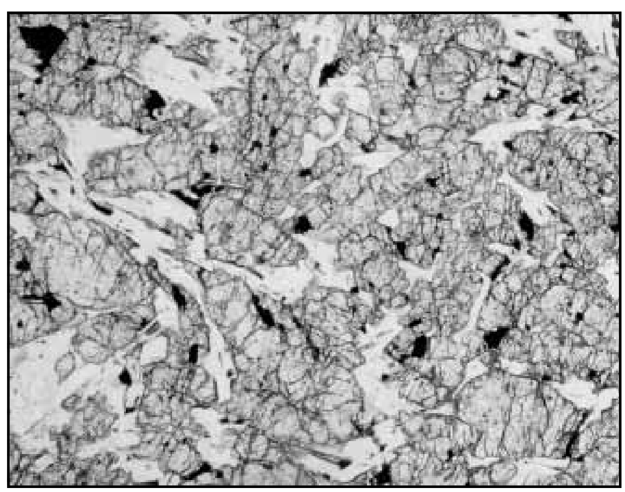

Figure IX-6. *Photomicrograph of thin section of EETA79001,79 illustrating the fine-grained matrix of lithology A. Field of view is 2.2 mm.*

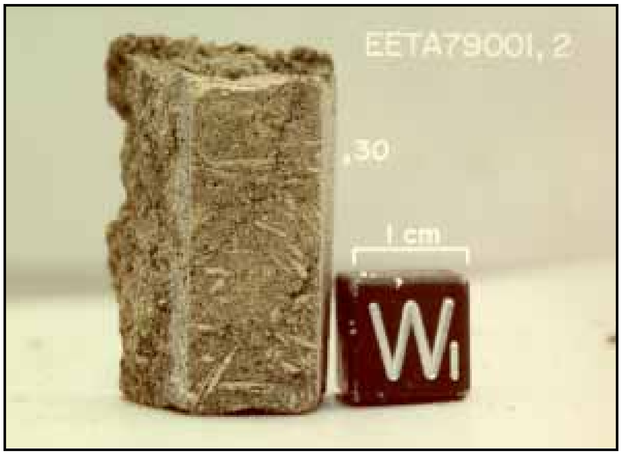

Figure IX-7. *Close-up photograph of sawn surface of EETA79001,30 illustrating the basaltic texture of lithology B. Cube is 1 cm for scale. (NASA # S81-25238)*

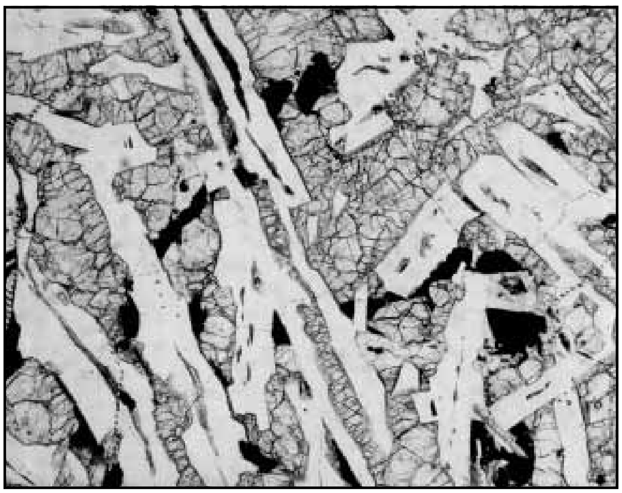

Figure IX-8. *Photomicrograph of thin section of EETA79001,88 illustrating basaltic texture of lithology B. Field of view is 2.2 mm.*

1994). Wadhwa *et al.* observed that orthopyroxene xenocrysts were often rimmed by coronas of pigeonite having the same composition as that in the groundmass, and that xenocrysts of olivine had irregular embayments cutting across internal zoning patterns (figure IX-9).

Two working hypotheses need to be considered. An igneous origin is argued by McSween and Jarosewich (1983) who conclude *"Both lithologies probably formed from successive volcanic flows or multiple injections of magma into a small, shallow chamber"*. However, the difference in I $^{87}Sr/^{86}Sr$ is proof that the two main lithologies (A and B) are not derived from the same source (see section on Radiometric Isotopes).

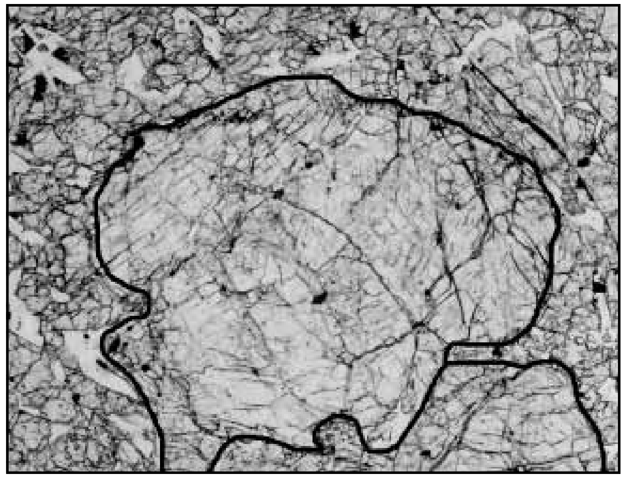

Figure IX-9. *Photomicrograph of thin section of EETA79001,79 illustrating a large olivine clast with irregular boundary in lithology A. Field of view is 2.2 mm.*

An alternative interpretation is that lithology A represents an impact melt rock that incorporates Lithology B, and the ultramafic clusters, as clasts (Mittlefehldt, personal communication). Simonds *et al*. (1976) developed a model for the formation of impact melt rocks which has been successful in explaining the textures of many rocks from the surface of the Moon (although they are more feldspathic) as well as for impact melt sheets found inside large terrestrial craters.

Key to the origin of EETA79001, is the observation of a gradational contact between lithology A and B (Steele and Smith, 1982b and McSween and Jarosewich, 1983)(figure IX-2). Is this contact a boundary between different lava flows, or is lithology B, instead, a clast in lithology A? The evidence in the literature is not clear on this point.

Lithology C is an assemblage of glass "pods" and thin, interconnecting, glass veins. Although lithology C has commonly been referred to as "glass," it actually consists of finely intermingled vitreous and cryptocrystalline materials (McSween and Jarosewich, 1983; Gooding and Muenow, 1986). Martinez and Gooding (1986) describe the true glassy part as dark brown to black, whereas the microcrystalline components include both dark gray-brown phases and colorless to white phases (figure IX-10). Both large vugs and small vesicles are common features. Some dark colored phases (probably pyroxenes) display quench textures that suggest origins by incomplete crystallization of the melt of this unit. In contrast, the light-colored phases might be a mixture of incompletely

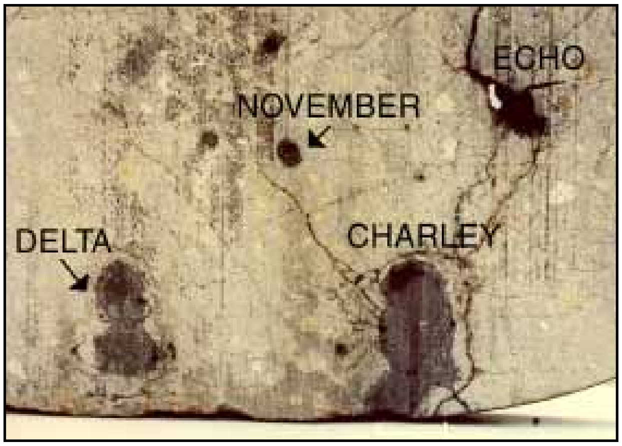

Figure IX-10. *Close-up photograph of a portion of slab EETA79001,22 illustrating several of the largest glass "pods" and interconnecting glass veins along cracks in lithology A. (NASA # S81-25257)*

melted relict grains and post-melting reaction products.

In 1983, Bogard and Johnson discovered high concentrations of rare gases (Ar, Ne, Kr, Xe) in portions of lithology C (*see section on Other Isotopes*). Figure IX-5 illustrates the "discovery pod" (,27) which contains a large (0.8 mm) vug or vesicle. Altogether there are more than 20 glass "pods" exposed on the sawn surfaces of EETA79001, with ~ 5 large ones (~1 cm). Most are found in lithology A, but one (PAPA) was studied from lithology B. Table IX-1 lists these glass pods and gives them each a new name in order to more clearly distinguish them. When the rock was sawn and broken, some of these glass pods broke free from the basaltic matrix. Nyquist *et al.* (1986) found that the I_{Sr} was significantly different for different "pods" (see section on Radiogenic Isotopes).

Thin black glass veins (~0.5 mm wide) extend from and connect various "pods" of black glass (Score *et al.*, 1982, McSween and Jarosewich, 1983). The composition of the dark brown vesicular glass veins and pods included in lithology A is similar to the bulk composition of lithology A (figure IX-11). However, two different glasses have been found in lithology B. Non-vesicular, clear glass varies in composition from maskelynite to bulk B and light-brown glass found to have a composition intermediate between bulk A and B.

Martinez and Gooding (1986) describe the "white druse" commonly found associated with lithology C in the interior of EETA79001 (figure IX-12). Martinez

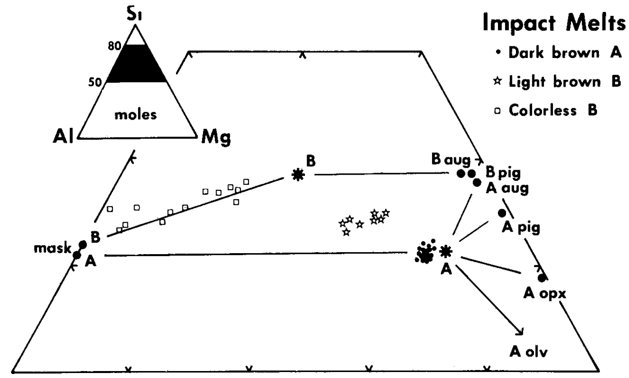

Figure IX-11. *Composition diagram for glass in EETA79001. Stars A and B are bulk compositions of lithology A and B respectively. The dark brown glass has a composition like that of the host rock, while the light brown and colorless glasses are along the join with the composition of maskelynite. This is figure 5 in McSween and Jarosewich (1983), GCA* ***47****, 1507.*

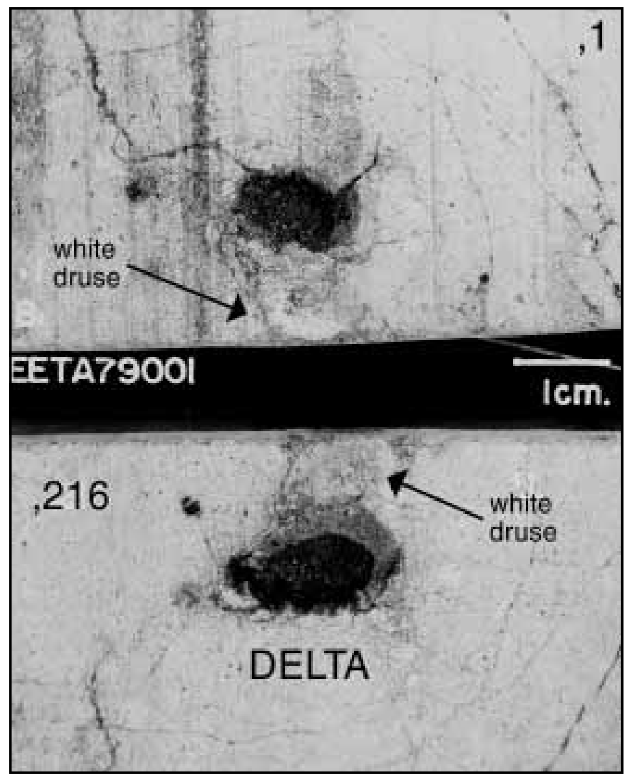

Figure IX-12. *The saw cut that separated ,216 and ,1 exposed another portion of glass pod "DELTA" in EETA79001. Note the concentric color change in the glass. Adjacent to this glass was a large deposit of white carbonate "druse" (sample ,239). (NASA # S86-37533)*

and Gooding describe this material to consist of *"thin saccharoidal coatings and veins of a colorless to white, translucent phase of dull to resinous luster."* Gooding and Muenow (1986), Wentworth and Gooding

Table IX-1. Glass pods (lithology C) and their locations in EETA79001.
(*see also figures IX-23 and 24*)

ALPHA - 8 mm, round, with vesicle - exposed by first saw cut on ,1 (figure S80-37631)
- piece ,8 broke free from ,2 before slab was cut
- portion (~1/2) remains on ,1 sawn surface

BRAVO - "discovery pod," studied by Bogard, Pepin, Swindle
- 1 cm, exposed by first sawcut on ,1
- large vug (7 mm)
- 1/2 piece ,27 broke free, part remains on ,22 (becomes ,120 -,126)
- Sr in ,27 by Nyquist (Sr 15.5 ppm)
- piece ,26 (PB) contains thin glass veins associated with ,27
- pieces ,120 - ,126, inc. ,122 Swindle (Hohenberg)
- ,245 studied by Wiens, 1988

CHARLEY (1 x 2.5 cm) - exposed by first sawcut - microcrystalline
- on ,1 and slab ,22 (did not extend thru slab ,22)
- contained in piece ,216 (at edge of both saw cuts 1980 and 1986)
- ,249 - ,257 from piece ,216
- closeup photo S81-25257 of CHARLEY, DELTA, ECHO on slab ,22
- exposed to outer surface of rock and surrounded by penetrating cracks
- Sr in ,186 by Nyquist (Sr 15 ppm)

DELTA - (dumbell-shaped pod) exposed by first sawcut - microcrystalline
- on ,1 and ,22 (did not extend thru slab ,22)
- exposed again by 1986 cut through ,1 again exposed on ,312
- contained in piece ,216 (at edge of both saw cuts 1980 and 1986)
- ,259 - ,263 from ,216
- cracks leading to outside surface S80-37631
- ,194 this half of glass "pod" was carefully lifted out of slab ,22
- "druse" salts studied by Gooding, Clayton, Wright (sample ,239)
- S86-37533 shows large patch of "white druse" adjacent to black glass
- black glass is surrounded by thick grey (altered) band in ,1
- minor orange "stain" seen in "white-druse"
- Sr in ,195 studied by Nyquist (Sr = 15 ppm)

ECHO
- large glass-lined cavity - seen initially on first saw cut on ,1 and ,2
- complex shape along open fracture, portion on ,52
- extends through slab ,22 and on ,312 (derived from ,2)
- ,54 ,56 ,57 derived from ,52 S81-25252, S90-34035, S93-33193
- penetrating cracks leading to CHARLEY and outer surface of rock
- possibly connecting to "regmaglypt" on exterior surface
- Sr in ,54 by Nyquist (17 ppm Sr)
- ,54 studied by Bogard *et al.*, 1984

FOXTROT
- 4 mm exposed on first cut S81-25268 S80-37631

GOLF
- 4 mm exposed by 1986 cut S86-26477

HOTEL
- 2 mm glass inclusion, near white inc. on ,38
- S81-25268 S81-25267

ITEM
- exposed by second saw cut from ,2 of backside of slab ,22
- 3 mm with 2 small vesicles exposed on ,312
- on edge of ,312 after break during small saw cut
- S81-25252

JULIET	- 3 mm with 2 mm vesicle - exposed on ,307 - S90-34035
LIMA	- small shinny black glass pod on ,309 - S90-34036
MIKE	- small pod exposed on ,311 and ,313 (exhibited by Smithsonian) - S90-34042 S90-34041
NOVEMBER	- small exposed by first saw cut ,1 and ,22 - ,197 studied by Nyquist (17 ppm Sr) - salts studied by Gooding
OSCAR	- small exposed first saw cut ,1 and ,22
PAPA	- Glass in lithology B - near outer surface - , 188 (from ,43) studied by Nyquist (30 ppm Sr) - TS ,71 and ,72 (from ,47) include glass from PAPA - S81-25259

(1986), Gooding *et al.* (1988) and Gooding and Wentworth (1991b) have studied the mineralogical composition of this material. "White druse" material has also been found along rock fractures (*e.g.* piece ,312). Photo S90-34041 of ,313 (display sample) shows a large off-white patch (8 mm) that may be an additional deposit of "druse." Gooding *et al.* (1988) showed that this material was mostly $CaCO_3$ (calcite), but also included $CaSO_4$. Isotopic data on the "druse" is discussed in the section on Other Isotopes.

Mineral Chemistry

Olivine**:** Olivine has a range of composition (Fo_{81-55}) in EETA79001 and contains a significant amount of NiO (~0.06%) (Steele and Smith, 1982b). The Fe/Mg of olivine appears to be in equilibrium with coexisting pyroxene. The olivine in the "megacrysts" in lithology A is the most Mg-rich (McSween and Jarosewich, 1983).

Pyroxene**:** There is a range of pyroxene compositions in EETA79001 (Steele and Smith, McSween and Jarosewich). Mg-rich orthopyroxene coexists with olivine in the "xenocyst clusters" in lithology A. In the groundmass of lithology A and B, zoned pigeonite and sub-calcic augite vary from Mg-rich to Fe-rich (figure IX-13 a and b). Wadhwa *et al.* (1994a) determined Y, Sc, Cr, Zr and Ti in the pyroxenes in EETA79001(figure IX-14). McSween and Jarosewich, and Steele and Smith, reported pyroxferroite in the mesostasis of lithology B, but gave no analysis.

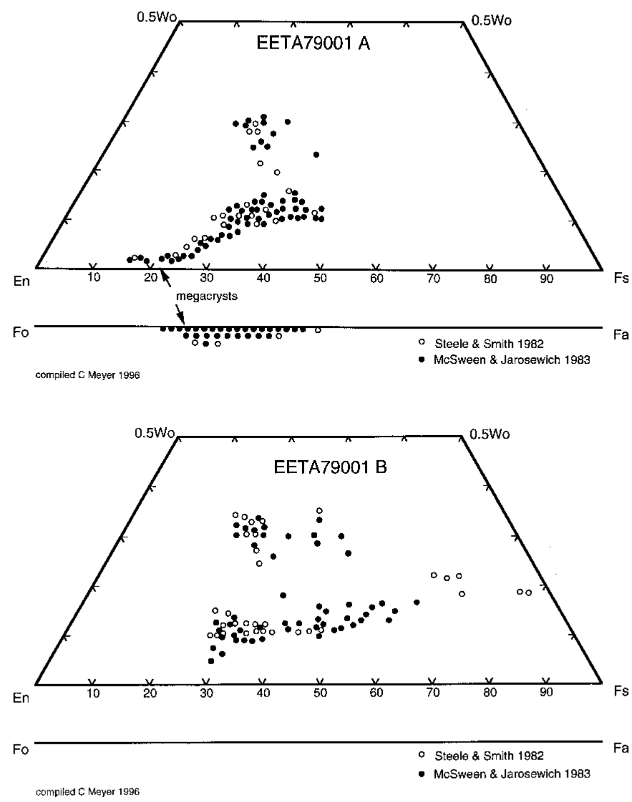

Figure IX-13. *Composition diagrams for pyroxenes in EETA79001, lithologies A and B. Note that the megacrysts in lithology A were the most magnesian. Data replotted from Steele and Smith (1979) and McSween and Jarosewich (1983).*

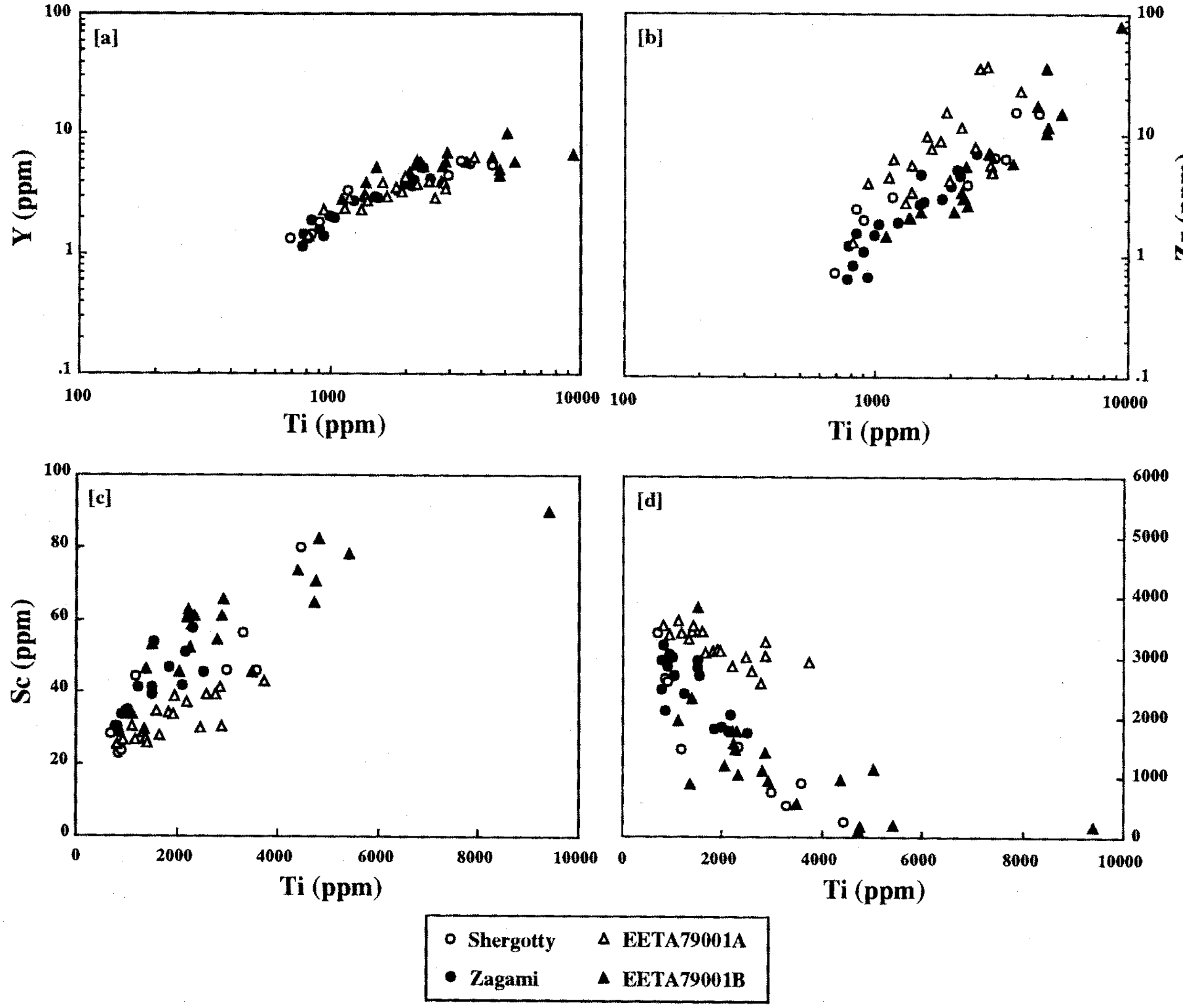

*Figure IX-14. Trace element (Ti, Y, Zr, Sc and Cr) contents of pyroxenes in basaltic shergottites. This is figure 4 from Wadhwa et al. (1994), GCA **58**,4219.*

***Plagioclase*:** Maskelynite grains generally fill interstices between clinopyroxene crystals in both lithologies, consistent with the interpretation that plagioclase crystallized after pyroxene. Plagioclase is An_{65}-An_{50} in both lithologies.

***Chromite*:** Chromite occurs as euhedral inclusions in the olivine in the "xenocryst clusters" in lithology A. Chromites are described as "two-phase" by Steele and Smith (1982b). One phase is low Ti, the other high Ti. *"About one-fifteenth of the total iron in the Ti-poor chromites, and one-ninth of that in the Ti-rich chromites, was converted to ferric iron to satisfy stoichiometry, again confirming the oxidizing conditions."*

***Ulvöspinel* and *ilmenite*:** These oxides are found in the mesostasis of lithology B. Steele and Smith (1982b), report that *"up to one-fifth of the iron was converted to ferric state."*

***Ringwoodite* (?) and *majorite* (?)** were tentatively reported in shock veins by Steele and Smith (1982b). These are high pressure polymorphs of olivine and pyroxene and give an indication of the shock pressure reached by this meteorite.

***Phosphate*:** Both whitlockite and Cl-apatite have been reported (Steele and Smith, 1982b). Wadhwa *et al.* (1994a) determined the REE content of whitlockites in several Shergottites and showed that they contained most of the REEs in these rocks.

***Sulfide*:** Steele and Smith (1982b) reported pyrrhotite $Fe_{0.91}S$. McSween and Jarosewich (1983) reported Ni in the sulfides in lithology A, but not in B. They also reported pentlandite.

***Carbonate*:** Calcium carbonate has been reported in the "white druse" (Gooding *et al*., 1988, Clayton and Mayeda, 1988, Wright *et al*., 1988) related to glass pod DELTA (sample ,239). X-ray diffraction by Gooding *et al.* established that this material was largely calcite.

***Other salts*:** Gooding (1992) summarized the various minor "salts," including sulfates and phosphates, found in EETA79001 and other Martian meteorites.

Glass: The composition of glass in EETA79001 has been reported in McSween and Jarosewich (1983). The glass pods and veins in lithology A generally have the composition of A and often contains secondary skeletal pyroxene crystals. In lithology B non-vesicular impact melt occurs between the pyroxene and maskelynite grains and varies in composition between bulk B and maskelynite (figure IX-11). Solberg and Burns (1989) could not find evidence of Fe^{+3} in lithology C using Mössbauer spectroscopy.

***SiO_2*:** McSween and Jarosewich (1983) reported tridymite (?) associated with pyroxferroite (?) in the mesostasis of lithology B.

Whole-rock Composition

Ma *et al*. (1982), McSween and Jarosewich (1983), Burghele *et al.* (1983), Smith *et al.* (1984) and Treiman *et al.* (1994a) give complete analyses of both lithologies A and B in EETA79001 (tables IX-2 and IX-3). The Fe/Mg ratio and Al, K, REE and P contents of lithology B are significantly higher than for lithology A. The Cr, Ni and Au contents are higher in lithology A than in B. Ir, Re and Os have not been determined accurately. The REEs are compared with other Martian meteorites in figure IX-15**.**

Gibson *et al.* (1985) reported 2540 ppm S in lithology A and 1940 ppm S in lithology B. Jovanovic and Reed (1987) reported 9.4 ppb Hg.

Gooding *et al*. (1990) determined the thermal release pattern for several volatile species. Karlsson *et al.* (1992) determined 640 ppm H_20 in lithology A, but some of this may be adsorbed terrestrial water. Leshin *et al.* (1996) showed that most water in lithology A was released before 350°C.

Note that the data for major element compositions of A and B in the review paper by McSween (1985) are in the wrong columns!

Radiogenic Isotopes

Wooden *et al.* (1982), reported Rb/Sr isochrons 173 ± 10 Ma with I $^{87}Sr/^{86}Sr$ = 0.71217 ± 3 for lithology A and 185 ± 25 Ma with I $^{87}Sr/^{86}Sr$ = 0.71243 ± 7 for lithology B (figure IX-16)(λ_{RB} = 1.39 x 10^{-11} $year^{-1}$). These apparent crystallization ages are the same as for the shergottites and ALHA77005, but the range in initial Sr ratios indicates separate source rocks.

Nyquist *et al.* (1984) analyzed hand-picked "mafic xenocrysts" from lithology A and found that they had I $^{87}Sr/^{86}Sr$ = 0.71187 ± 7 (calculated for 180 Ma). However, Nyquist later revised this number to be on the isochron (personal communication). Nyquist *et al.* (1986) analyzed the I $^{87}Sr/^{86}Sr$ in glass inclusions (lithology C) and found that they were heterogeneous (figure IX-17)**.**

Nyquist *et al.* (1984) also reported a Sm-Nd isochron age for pyroxene - whole rock as 240 ± 150 Ma, but made no further reference to this age in Nyquist *et al.* (1986). Wooden *et al.* (1982) determined the Sm-Nd model age of 2.6 Ga.

By leaching "whole-rock" samples of EETA79001, Chen and Wasserburg (1986a) obtained a U-Pb "isochron" of 150 ± 15 Ma and a Th-Pb "isochron" of 170 ± 36 Ma. These leach experiments probably attacked the phosphates in the sample.

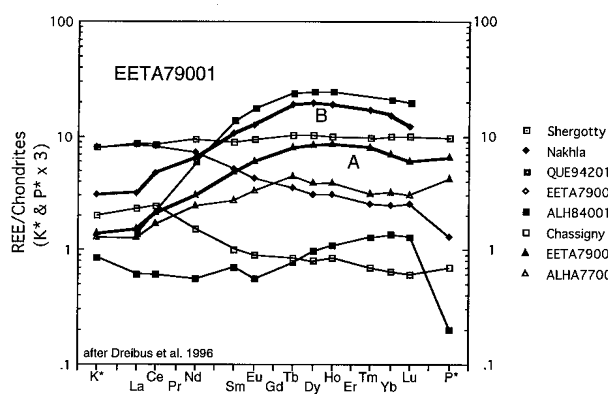

Figure IX-15. *Normalized rare earth element contents in EETA79001 lithology A and B compared with other Martian meteorites. Note the depletion in light REE. This figure is redrafted from Dreibus et al. (1996).*

Table IX-2. Chemical analyses of EETA 79001 A.

	McSween 83	**Burghele 83**	**Smith 84**	**Treiman 94a**	**Laul 86**	**Ma 82**
weight			*310 mg*	*67 mg **	*310 mg*	*310 mg*
SiO_2 %	48.52 (a)	48.58 (b)				
TiO_2	0.7 (a)	0.64 (b)	0.6 (d)		0.6 (d)	0.6 (d)
Al_2O_3	5.68 (a)	5.37 (b)	5.6 (d)		5.6 (d)	5.6 (d)
Fe_2O_3	0.7 (a)					
FeO	17.94 (a)	18.32 (b)	19.1 (d)	18.4 (d)	19 (d)	19.2 (d)
MnO	0.52 (a)	0.469 (b)	0.47 (d)		0.47 (d)	0.469 (d)
CaO	7.1 (a)	7.05 (b)	6.9 (d)	7 (d)	6.9 (d)	6.9 (d)
MgO	16.59 (a)	16.31 (b)	16.3 (d)		16.3 (d)	16.3 (d)
Na_2O	0.84 (a)	0.818 (b)	0.87 (d)	0.92 (d)	0.86 (d)	0.87 (d)
K_2O	0.05 (a)	0.033 (b)	0.042 (d)		0.042 (d)	0.04 (d)
P_2O_3	0.65 (a)	0.54 (b)				
sum	**99.29**	**98.13 (b)**				
Li ppm		4.54 (b)				
C	200	36 (b)				
F		39 (b)				
S	1784 (g)	1600 (b)				
Cl		26 (b)				
Sc		36.1 (b)	37 (d)	37 (d)	36 (d)	37 (d)
V			210 (d)		210 (d)	210 (d)
Cr	3968 (a)	4030 (b)	4173 (d)	4392 (d)	4173 (d)	4173 (d)
Co		47.3 (b)	48 (c)	48.9 (d)	45 (d)	48 (d)
Ni	300	158 (b)	140 (d)	160 (d)		150 (d)
Cu						
Zn		81 (b)	64 (c)		70 (d)	
Ga		12.6 (b)	13 (c)			
Ge						
As		0.005 (b)	0.044 (c)			
Se		<.8 (b)	0.43 (c)	0.5 (d)		
Br		0.189 (e)				
Rb			1.04 (c)			
Sr		57 (b)	57			
Y						
Zr						
Nb						
Mo						
Pd ppb						
Ag ppb			19 (d)			
Cd ppb			37 (c)			
In ppb			46 (c)			
Sb ppb		<10 (b)	10 (c)			
Te ppb			5.9 (c)			
I ppm		<0.1 (b)				
Cs ppm			0.075 (c)	0.07 (d)		
Ba		<10 (b)				
La		0.37 (b)	0.41 (d)	0.32 (d)	0.41 (c)	0.42 (d)
Ce		1.4 (b)	<0.5 (d)	1.4 (d)	1 (c)	
Pr						
Nd		1.4 (b)			1.3 (c)	
Sm		0.75 (b)	0.74 (d)	0.64 (d)	0.78 (c)	0.78 (d)
Eu		0.35 (b)	0.37 (d)	0.331 (d)	0.37 (c)	0.38 (d)
Gd						
Tb		0.3 (b)	0.26 (d)	0.25 (d)	0.34 (c)	0.24 (d)
Dy		2.11 (b)	1.7 (d)			1.7 (d)
Ho		0.5 (b)			0.5 (c)	
Er						
Tm		0.21 (b)	0.11 (d)		0.22 (c)	
Yb		1.12 (b)	1.1 (d)	1.03 (d)	1.25 (c)	1.11 (d)
Lu		0.15 (b)	0.18 (d)	0.14 (d)	0.18 (c)	0.19 (d)
Hf		0.93 (b)	0.94 (d)	0.97 (d)	0.94 (c)	0.97 (d)
Ta		0.03 (b)	<0.05 (d)	0.03 (d)		
W ppb		83 (b)				
Re ppb						
Os ppb						
Ir ppb		<2 (b)				
Au ppb		2.8 (b)	3.9 (c)	18 (d)		
Tl ppb			6.9 (c)			
Bi ppb	**Chen 86**		0.67 (c)			
Th ppm	0.08 (f)	<.1 (b)				
U ppm	0.018 (f)	<.06 (b)				

technique: (a) wet chem., (b) INAA & RNAA, (c) RNAA, (d) INAA, (e) Dreibus et al 1985, (f) isotope dilution mass spec.
(g) recalculated
** from powder prepared by Jarosewich*

Table IX-3. Chemical analyses of EETA 79001 B.

	McSween 83	Burghele 83	Smith 84	Treiman 94a	Laul 86	Dreibus 96	Ma 82
weight		*232.7*	*301 mg*	*71 mg **	*301 mg*		301 mg
SiO2 %	49.03 (a)	49.03 (b)					
TiO2	1.23 (a)	1.12 (b)	1.1 (d)		1.1 (d)		1.1 (d)
Al2O3	9.93 (a)	9.93 (b)	10.5 (d)		10.5 (d)		10.5 (d)
Fe2O3	0.22 (a)						
FeO	16.87 (a)	17.74 (b)	17.9 (d)	17.3 (d)	17.9 (d)		17.9 (d)
MnO	0.47 (a)	0.452 (b)	0.41 (d)		0.41 (d)		0.413 (d)
CaO	11 (a)	10.99 (b)	10.4 (d)	11.3 (d)	10.4 (d)		10.4 (d)
MgO	7.32 (a)	7.38 (b)	7.5 (d)		7.5 (d)		7.5 (d)
Na2O	1.68 (a)	1.66 (b)	1.62 (d)	1.69 (d)	1.62 (d)		1.62 (d)
K2O	0.09 (a)	0.065 (b)	0.075 (d)		0.075 (d)		0.07 (d)
P2O3	1.25 (a)	1.31 (b)					
sum	**99.09**	**99.677**					
Li ppm		2.21 (b)					
C	100	98 (b)					
F		30.9 (b)					
S	2184 (f)	1920 (b)					
Cl		48 (b)					
Sc		50.5 (b)	50 (d)	50.1 (d)	50 (d)		50 (d)
V			206 (d)		206 (d)		206 (d)
Cr	957 (a)	1252 (b)		1273 (d)	1197		
Co	<100	31.1 (b)	30 (c)	30.8 (d)	30 (d)		30 (d)
Ni	<100	46 (b)	30 (d)	50 (d)			20 (d)
Cu							
Zn		120 (b)	71 (c)		71 (d)		
Ga		24.4 (b)	17 (c)				
Ge							
As		0.012 (b)	0.021 (c)				
Se			0.42 (c)	0.4 (d)			
Br		0.289 (e)					
Rb			1.78 (c)				
Sr		67 (b)	67	40 (d)			
Y						27.8 (g)	
Zr						64.8 (g)	
Nb						1.66 (g)	
Mo							
Pd ppb							
Ag ppb			6.3 (c)				
Cd ppb			70 (c)				
In ppb			68 (c)				
Sb ppb		<30 (b)	16 (c)				
Te ppb			7.4 (c)				
I ppm		0.96 (b)					
Cs ppm			0.131 (c)	0.13 (d)			
Ba		14 (b)				12 (g)	
La		0.8 (b)	0.81	0.68 (d)	0.88 (c)	0.781 (g)	0.82 (d)
Ce		3.1 (b)	2.2	1.6 (d)	2.2 (c)	2 (g)	
Pr							
Nd		2.9 (b)	3		2.5 (c)	2.12 (g)	3 (d)
Sm		1.56 (b)	1.5	1.28 (d)	1.65 (c)	1.43 (g)	1.5 (d)
Eu		0.73 (b)	0.72		0.72 (c)	0.67 (g)	0.72 (d)
Gd					3.2 (c)	2 (g)	
Tb		0.64 (b)	0.57	0.64 (d)	0.71 (c)	0.48 (g)	0.55 (d)
Dy		4.58 (b)	3.7			3 (g)	3.7 (d)
Ho		0.99 (b)			0.98 (c)	0.71 (g)	
Er							
Tm		0.37 (b)	0.27		0.4 (c)		
Yb		2.14 (b)	2	1.81 (d)	2.3 (c)	1.85 (g)	2.04 (d)
Lu		0.3 (b)	0.3	0.25 (d)	0.32 (c)	0.26 (g)	0.3 (d)
Hf		1.93 (b)	1.77	1.78 (d)	1.77	1.84 (g)	1.81 (d)
Ta		0.09 (b)	0.09	0.06 (d)			
W ppb		155 (b)					
Re ppb							
Os ppb							
Ir ppb		<3 (b)					
Au ppb		1.1 (b)	0.82 (c)				
Tl ppb			7.9 (c)				
Bi ppb			0.76 (c)				
Th ppm		<0.2 (b)				0.144 (g)	
U ppm		<0.1 (b)		0.11 (d)		0.0366(g)	

technique: (a) wet chem., (b) INAA & RNAA, (c) RNAA, (d) INAA, (e) Dreibus et al 1985, (f) recalculated (g) spark source mass spec
** from powder prepared by Jarosewich*

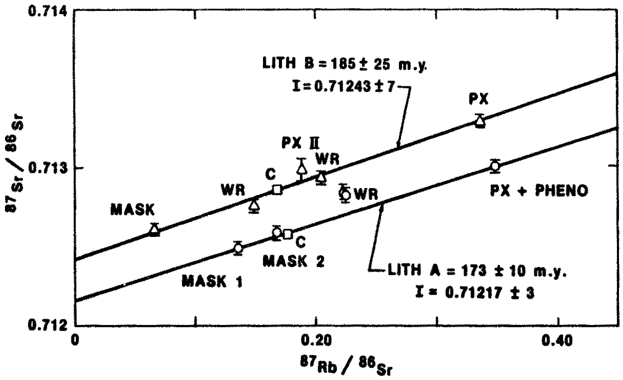

Figure IX-16. Rb-Sr isochron diagram for mineral separates and whole rock samples from lithology A and B in EETA79001. This is figure 1 from abstract by Wooden et al. (1982), LPS XIII, page 880.

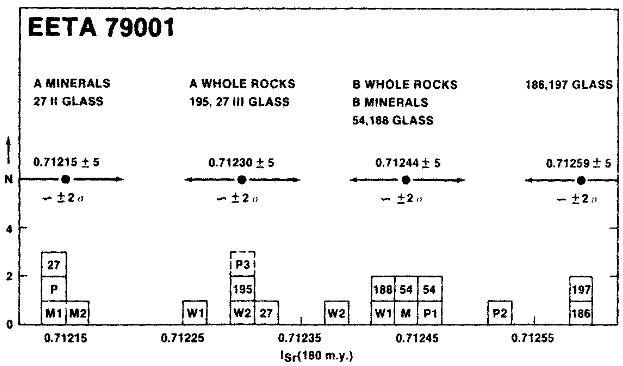

Figure IX-17. Initial Sr isotopic composition of different glass "pods" in EETA79001. This is figure 4 in abstract by Nyquist et al. (1986), LPS XVI, page 625.

Compiler's Note: This rock has multiple features that require dating. First, there was an event that made the source region for the materials in this rock. Then, there were two igneous events when lithologies A and B crystallized. Later, there was a shock event that converted the plagioclase into maskelynite and perhaps another shock event that formed the glass pods and veins and also trapping the Martian atmosphere. There may have been a time when the rock was altered by fluids on Mars — forming the salts observed in the voids. Finally, there was an event that launched this rock from Mars, and perhaps a time of breakup on its way to Earth. Which age goes with which event?

Cosmogenic Isotopes and Exposure Ages

Jull and Donahue (1988) give a terrestrial exposure age of 12 ± 2 thousand years using ^{14}C. However Sarafin *et al.* (1985) reported a "terrestrial residence time" of 320 ± 170 thousand years based on ^{26}Al, ^{10}Be and ^{53}Mn data. Nishiizumi *et al.* (1986) set a limit of <60 thousand years using ^{36}Cl on a deep sample (2.5 cm).

Bogard *et al.* (1984b) determined a cosmic-ray exposure age of ~0.5 Ma. Sarafin *et al.* (1985) reported an exposure age of 0.78 ± 0.14 Ma. Nishiizumi *et al.* (1986) reported an exposure age of 0.6 Ma. Pal *et al.* (1986) determined exposure ages of 0.73 ± 0.19 Ma for lithology A and 0.9 ± 0.17 Ma for lithology B using ^{10}Be.

Other Isotopes

This is the rock that demonstrated the Martian origin for SNC meteorites (*see* Pepin, 1985, Hunten *et al.*, 1987 or a review by McSween, 1985, 1994). In glass pockets of this meteorite, Bogard and Johnson (1983) and Bogard *et al.* (1984b) found high concentrations of rare gasses and determined that the ratios $^{84}Kr/^{132}Xe$ ~15, $^{40}Ar/^{36}Ar$ > 2000, $^{129}Xe/^{132}Xe$ >2 and $^{4}He/^{40}Ar$ < 0.1 were significantly different than the rare gas component of any other meteorite, but indeed similar to the rare gas analysis made by the Viking spacecraft on Mars (figure I-1). Becker and Pepin (1984) extended this observation to $^{15}N/^{14}N$ and N/Ar ratios. Ott and Begemann (1985), Wiens (1988) and others have extended and confirmed these measurements (see also Marti et al. (1995) for similar data on Zagami).

Clayton and Mayeda (1983, 1996) reported the oxygen isotopes for EETA79001 A and B (figure I-2). Romanek *et al.* (1996) reported additional data for oxygen isotopes using their newly developed laser-fluoridation technique.

Carr *et al.* (1985) calculated a heavy ^{13}C component ($\delta^{13}C$ = +36 ‰) for the gas found in the high temperature release of lithology C in EETA79001 which may be from the atmosphere on Mars. However, this was based on very small amounts of carbon.

Clayton and Mayeda (1988) and Wright *et al.* (1988) determined $\delta^{13}C$ and $\delta^{18}O$ for "calcite" dissolved by phosphoric acid in "white druse" material supplied by Gooding (figure IX-12, sample ,239). These authors concluded the "druse" was a product of extra-terrestrial origin (*i.e.* alteration on Mars). Jull *et al.* (1992) studied a different sample of "druse" (,320) and found that it contained significant ^{14}C, which requires a terrestrial origin.

Isotopic Results on "White-Druse"

	$\delta^{13}C$	$\delta^{18}O$	^{14}C	$\delta^{15}N$
Clayton and Mayeda (1988)	+9.7 ‰	+21.0 ‰		
Wright *et al.* (1988)	+6.8 ‰	+21.0 ‰		~0 ‰
Jull *et al.* (1992)	+3.1 ‰	+20.0 ‰	*high activity*	
Douglas *et al*. (1994)	+7.2 and -28.6 ‰			

Wright *et al*. (1988) and Grady *et al*. (1995a) found that the nitrogen released from EETA79001 or its "druse" (carbonates) was not enriched in $\delta^{15}N$ and the apparent nitrates in these salts could not have formed by oxidation of the Martian atmosphere. Since the nitrates, carbonates and sulfates are all part of the same mineral assemblage, this also apparently creates a problem for a Martian origin of these salts.

Leshin *et al*. (1996) extracted the water out of EETA79001 and measured the isotopic ratio of hydrogen at several temperature steps (figure V-13).

Chen and Wasserburg (1986) reported the Pb isotopes in EETA79001 and concluded that the parent body (Mars) was enriched in ^{204}Pb and (probably) other volatiles.

Organics (?)

Wright *et al.* (1989) and Gooding *et al*. (1990) reported organic compounds released during heating. Gooding *et al*. recognized that the trace organic concentration in their sample was not above background as determined on blanks (Gooding, 1992). However, the low temperature release sample studied by Wright *et al.* (EETA79001,239) was reported to have ~ 1,000 ppm C with an isotopically light signature ($\delta^{13}C$ = -30 ‰). Douglas *et al*. (1994) confirmed this result in a second sample (EETA79001,323) and stated *"if the carbonaceous components in 239 and 323 are truely martian organics, the implications for our understanding of Mars are immense."*

McDonald and Bada (1995) analyzed samples of "white druse" and lithology A from EETA79001 for amino acids and found approximately 1 ppm and 0.4 ppm respectively. However the amino acids detected were almost exclusively L-enantiomers commonly found in proteins and thus terrestrial contamination. They also found that the amino acids in clean Antarctic ice were of the same kind and concluded that the "white druse" could have been contaminated by organics from melt water in Antarctica.

The possibility of organic contamination by Xylan used as a lubicant in the processing cabinets was examined and ruled out by Wright *et al.* (1992g). The possibility of bacterial action was pointed out by Ivanov *et al.* (1992).

Shock Effects

Stöffler *et al.* (1986) determined that EETA79001 reached a shock pressure of 34 ± 1 GPa with post-shock temperature about 250°C. McSween and Jarosewich (1983) pointed out that bulk melting of lithology A, as indicated by the composition of the glass pods and veins, indicates shock pressures in excess of 80 GPa (Schaal and Hörz, 1977). The shock event that blasted this rock off Mars was apparently not intense enough to cause decrepidation of the carbonate salts (Gooding *et al.,* 1988).

Experiments

Jones *et al.* (1991) performed melting experiments on the composition of the groundmass of lithology A, EETA79001. Longhi and Pan (1989) have summarized the experimental work on shergottites.

Processing

The processing of EETA79001 has proceeded along the lines of a 3D jigsaw puzzle (figures IX-18 and IX-19). In 1980, a slab was cut from the center of the meteorite, along the long dimension of the rock, creating two large pieces (,1 and ,2) and a cm thick slab that broke into two pieces (,21 and ,22). Most initial allocations were made from these slab pieces (figure IX-20). In 1986, a third cut was made perpendicular to the 1980 cuts, dividing ,1 into two pieces (the big piece ,1 and ,216). Lithological maps of these sawn surfaces are figures IX-21 a and b (Martinez and Gooding, 1986). In 1990, the remaining large piece (,2) was further cut to create three pieces (big piece ,2, middle piece ,307, and end

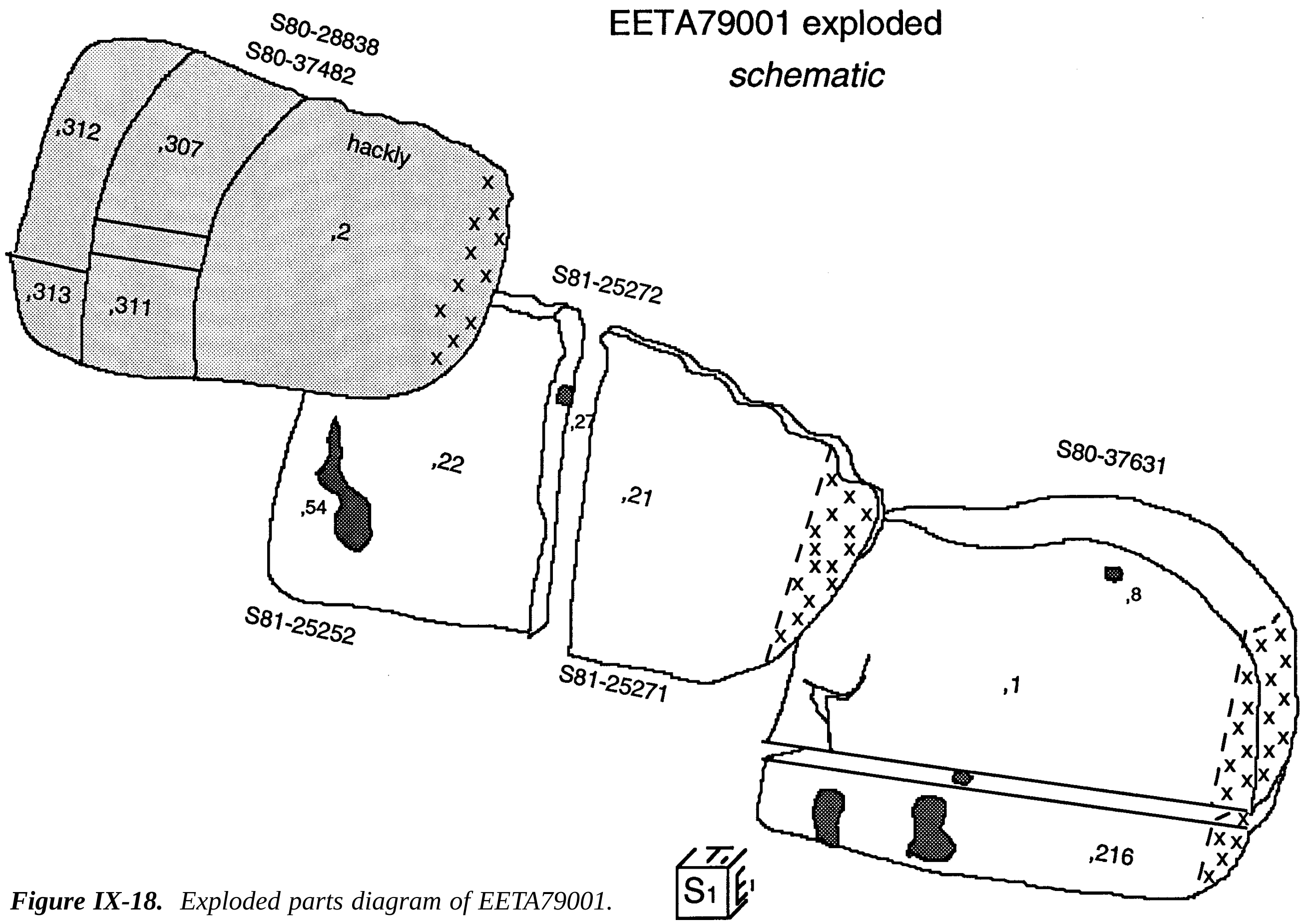

Figure IX-18. *Exploded parts diagram of EETA79001.*

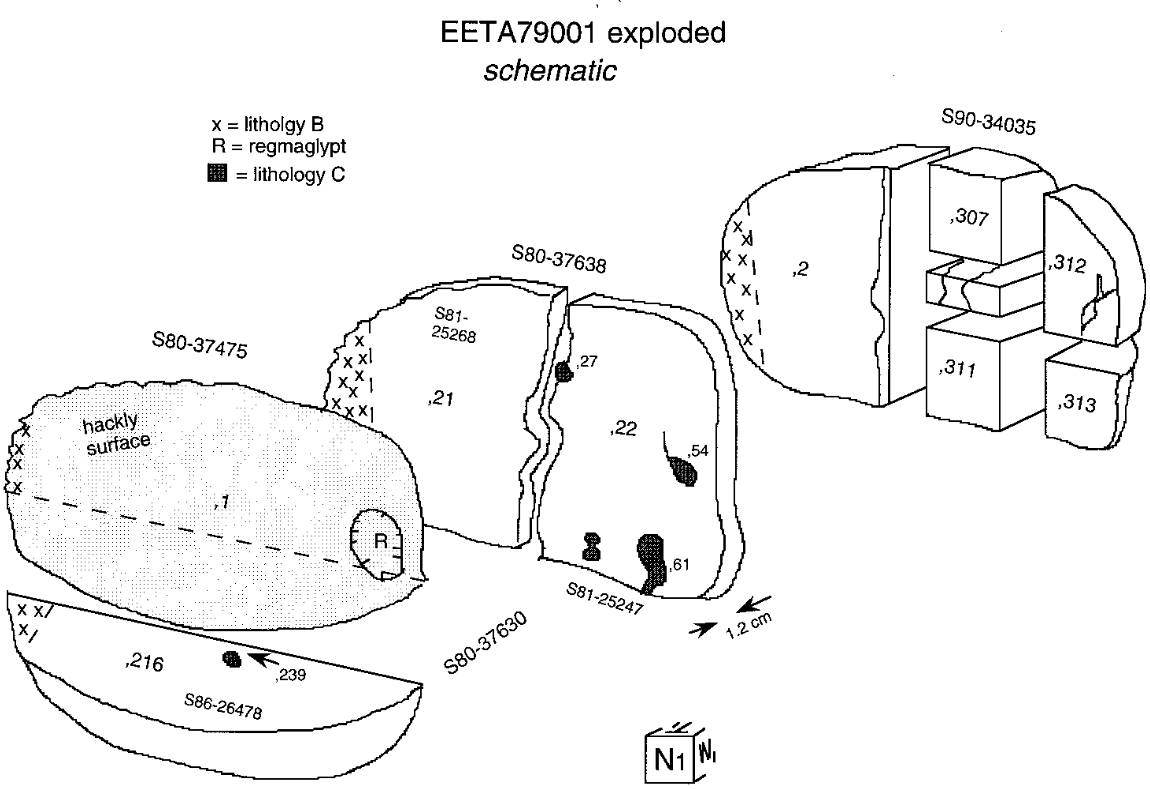

Figure IX-19. *Exploded parts diagram of EETA79001 (reversed).*

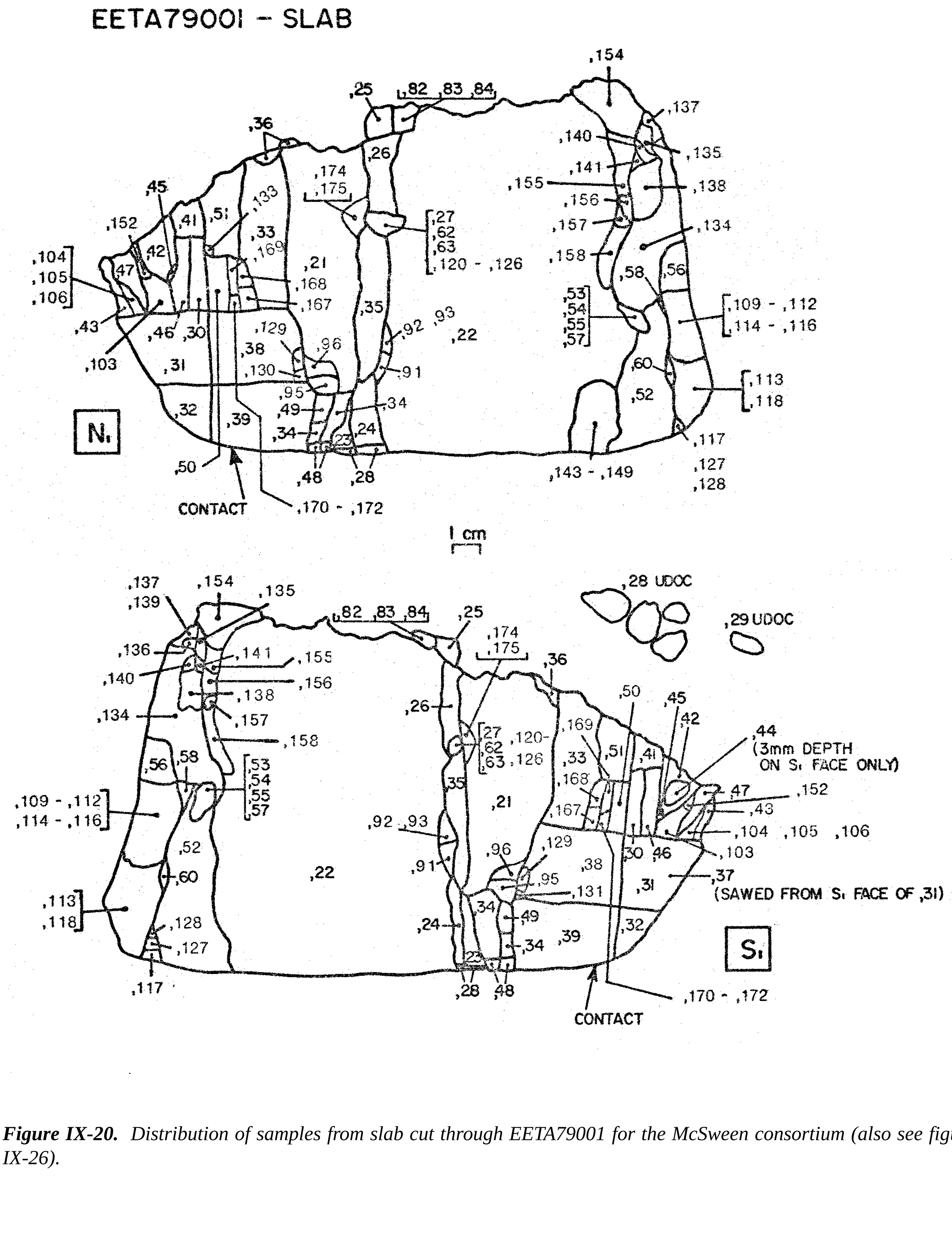

Figure IX-20. Distribution of samples from slab cut through EETA79001 for the McSween consortium (also see figure IX-26).

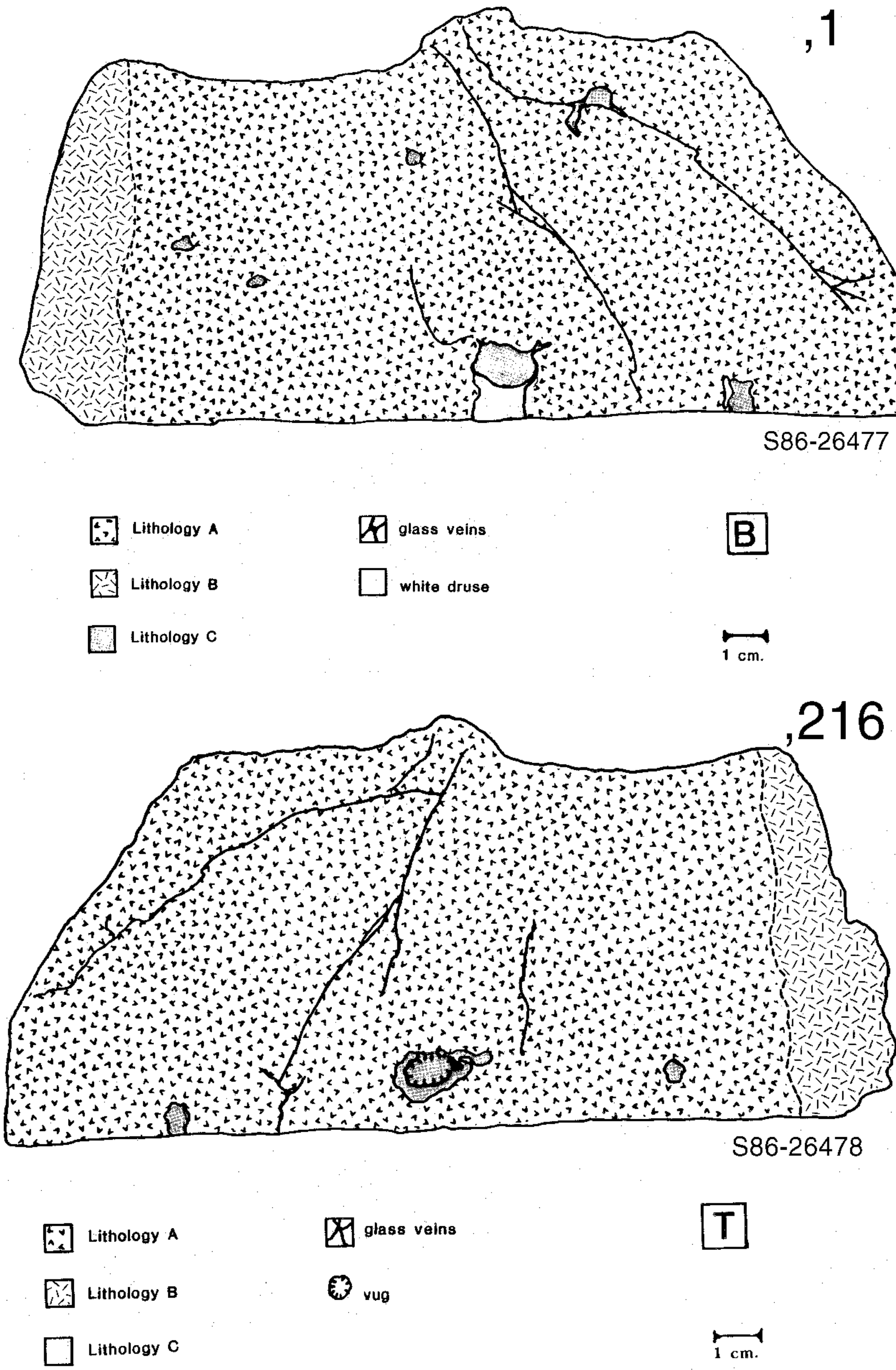

Figure IX-21. Lithological maps of large sawn surface of EETA79001,216 and opposing side of ,1. Drawings by Rene Martinez and James L. Gooding (1986).

piece ,312). A small slab ,310 was created from the center of ,307 leaving end pieces ,307 and ,311. Piece ,313 was also cut from ,312 and adjacent to ,311. Adjacent samples ,311 and ,313 (end pieces with fusion crust) were sent to the Smithsonian (USNM) for public display. The remainder of ,307 was allocated to NASA as a display specimen.

This sample was the subject of a consortium led by Hap McSween (see McSween and Jarosewich, 1983, McSween, 1985). In 1980, homogenized powders were prepared by Jarosewich of both lithology A (15g) and B (9g) (see Jarosewich, 1990b). These powders are available to investigators by request to MWG.

Lithology B (~400 grams) was located at one end of the specimen and is now on pieces ,1 ,2 ,216 and slab piece ,21 (figure IX-22).

Lithology C is represented by many different glass "pods" (table IX-2, figure IX-23 and IX-24) and thin glass veins. Sample ,8 (ALPHA) was the first large glass inclusion studied. Sample ,27 (BRAVO) is a piece of one of the large glass inclusions (lithology C) where the evidence of trapped Martian atmosphere was first found (figure IX-5). The first saw cut went right through this glass inclusion leaving a portion of it attached to ,1. It contained a large glass-lined vug. Much of sample ,27 broke free from the boundary of slabs ,21 and ,22.

In order to provide some clarity to the allocation of this large sample, figures IX-25 and IX-26 of the various splits are provided. However, these two diagrams are not complete and one must refer to the meteorite data base (JSC). Table IX-4 gives the current location of the 66 thin section that have been made of this rock. The NASA-Smithsonian Educational Thin Section sets include EETA79001 (French *et al.,* 1990).

Please note that the orientation cube in photos taken in 1990 and 1993 was placed in the wrong orientation (reversed).

Lithologies B and C are listed as "*restricted*" samples by the MWG (Score and Lindstrom, 1993, page 5).

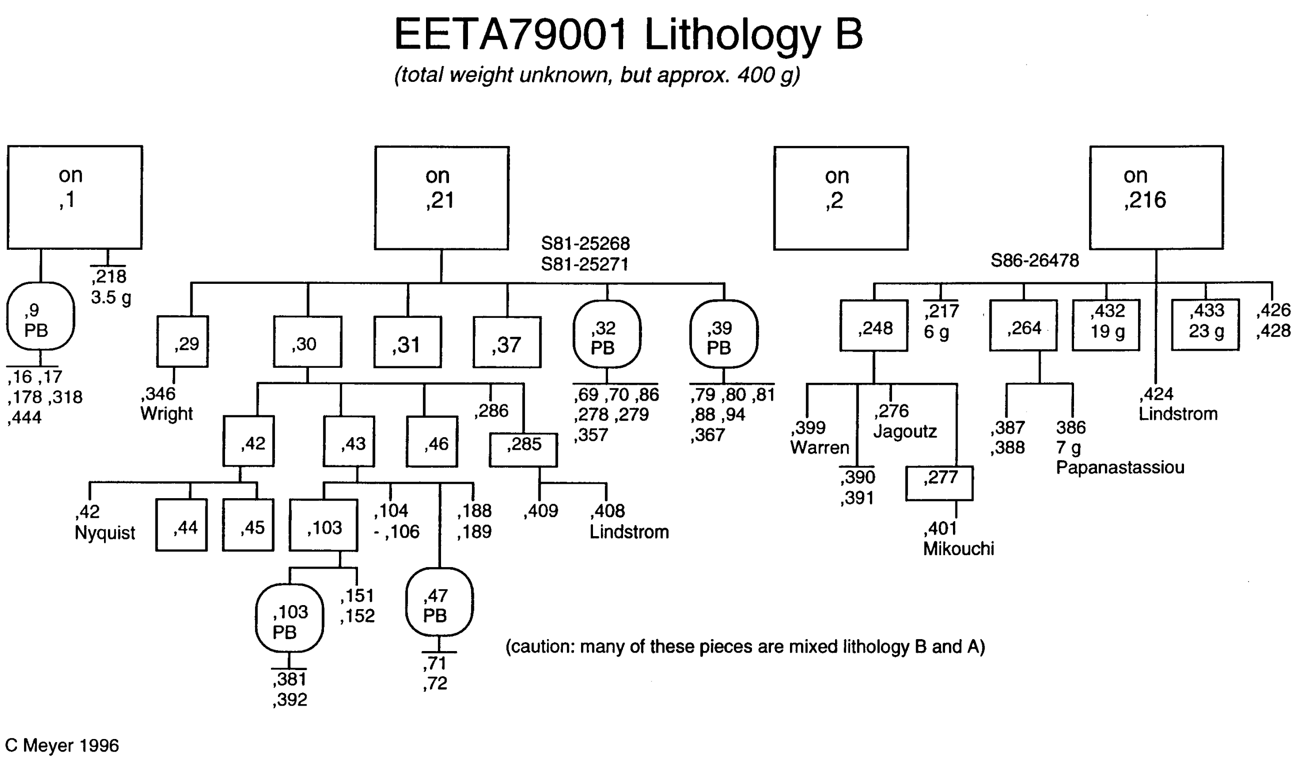

Figure IX-22. *Partial genealogy diagram for lithology B of EETA79001 showing relationship between various subsamples.*

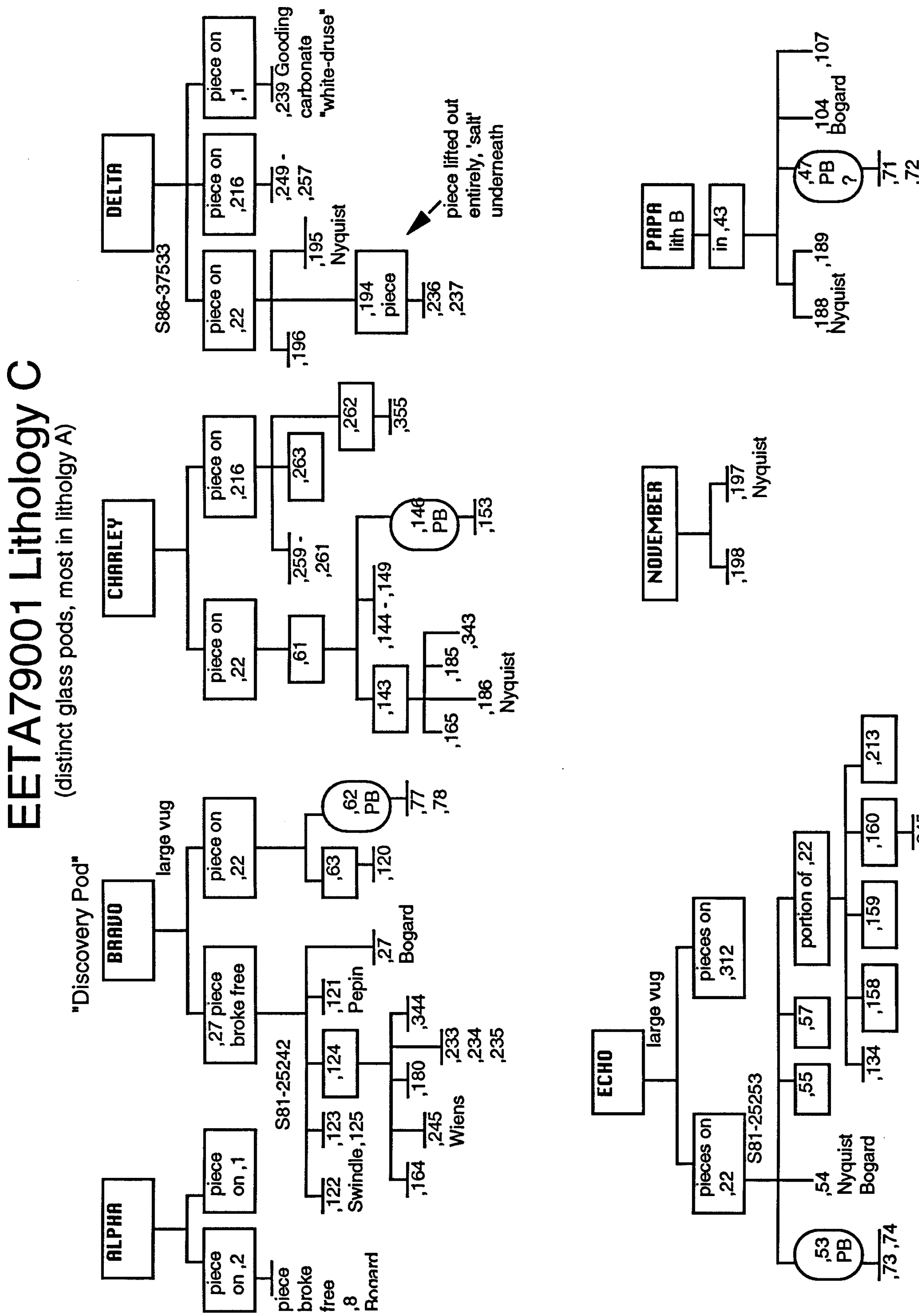

Figure IX-23. *Partial genealogy diagram for lithology C of EETA79001 showing relationship between various subsamples (see also table IX-1).*

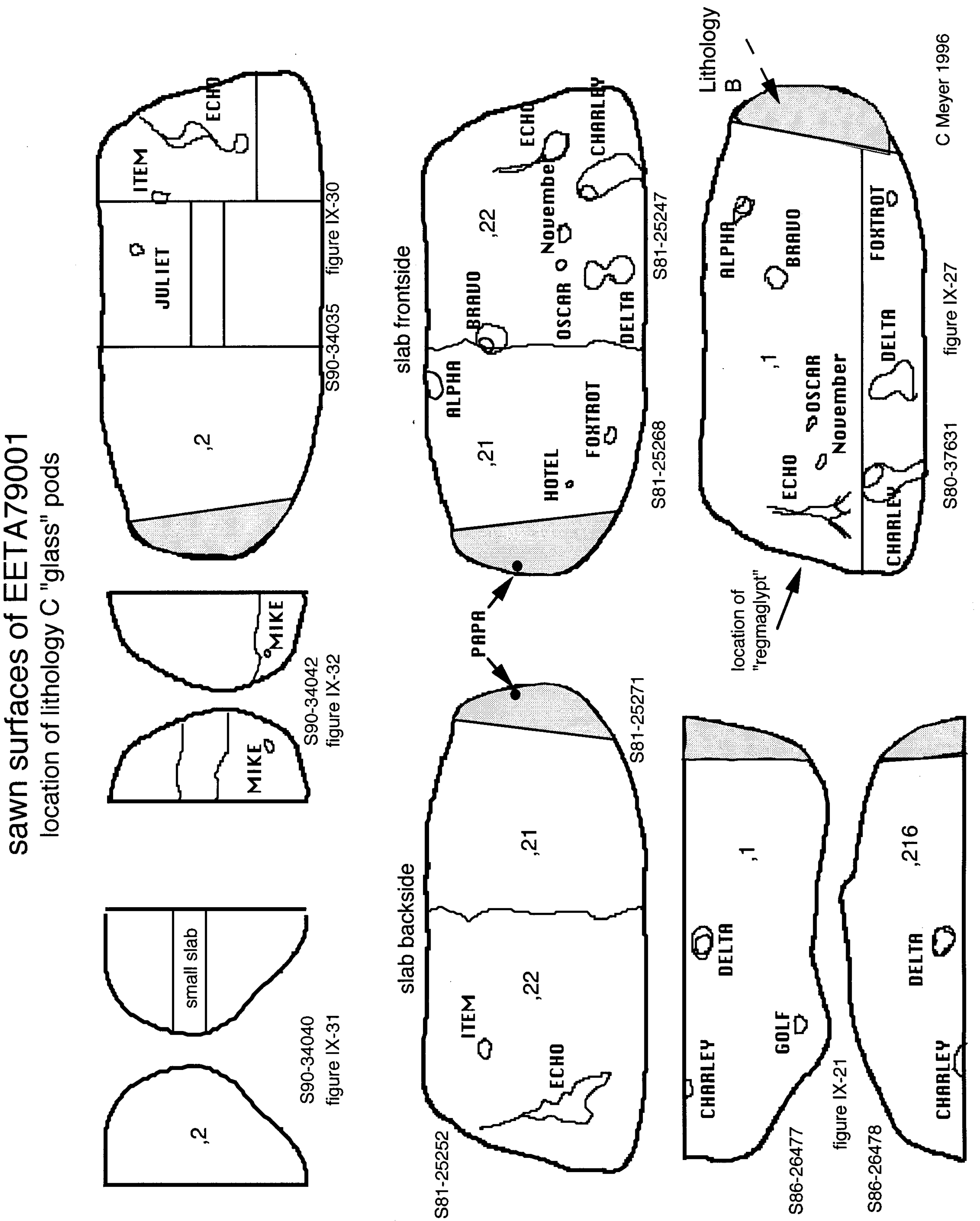

Figure IX-24. *Location of glass "pods" on sawn surfaces of EETA79001. See also table IX-1.*

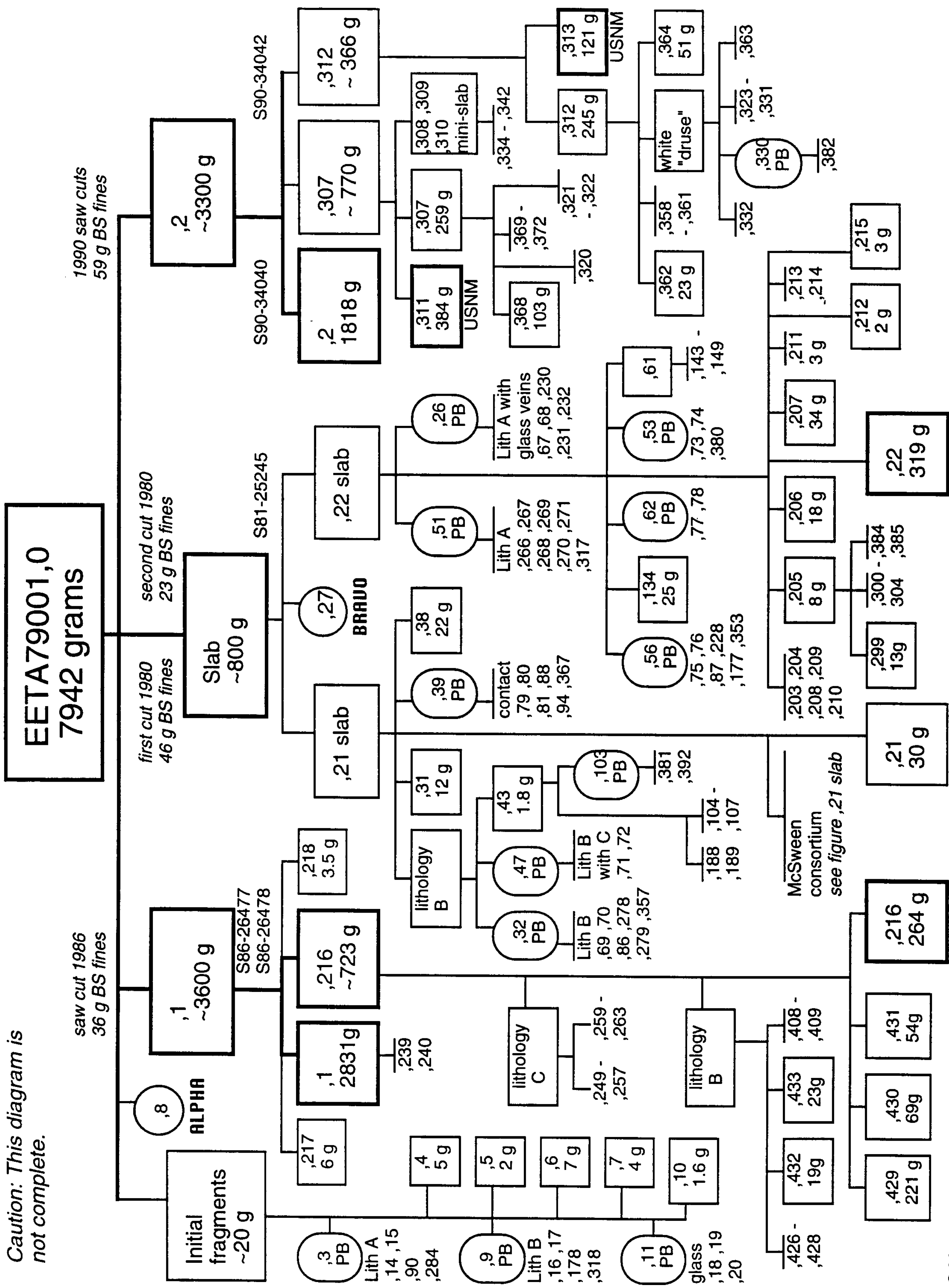

Figure IX-25. *Genealogy diagram for splits of EETA97001 showing relationship of samples studied and opportunities for future research. Note that this diagram is not complete.*

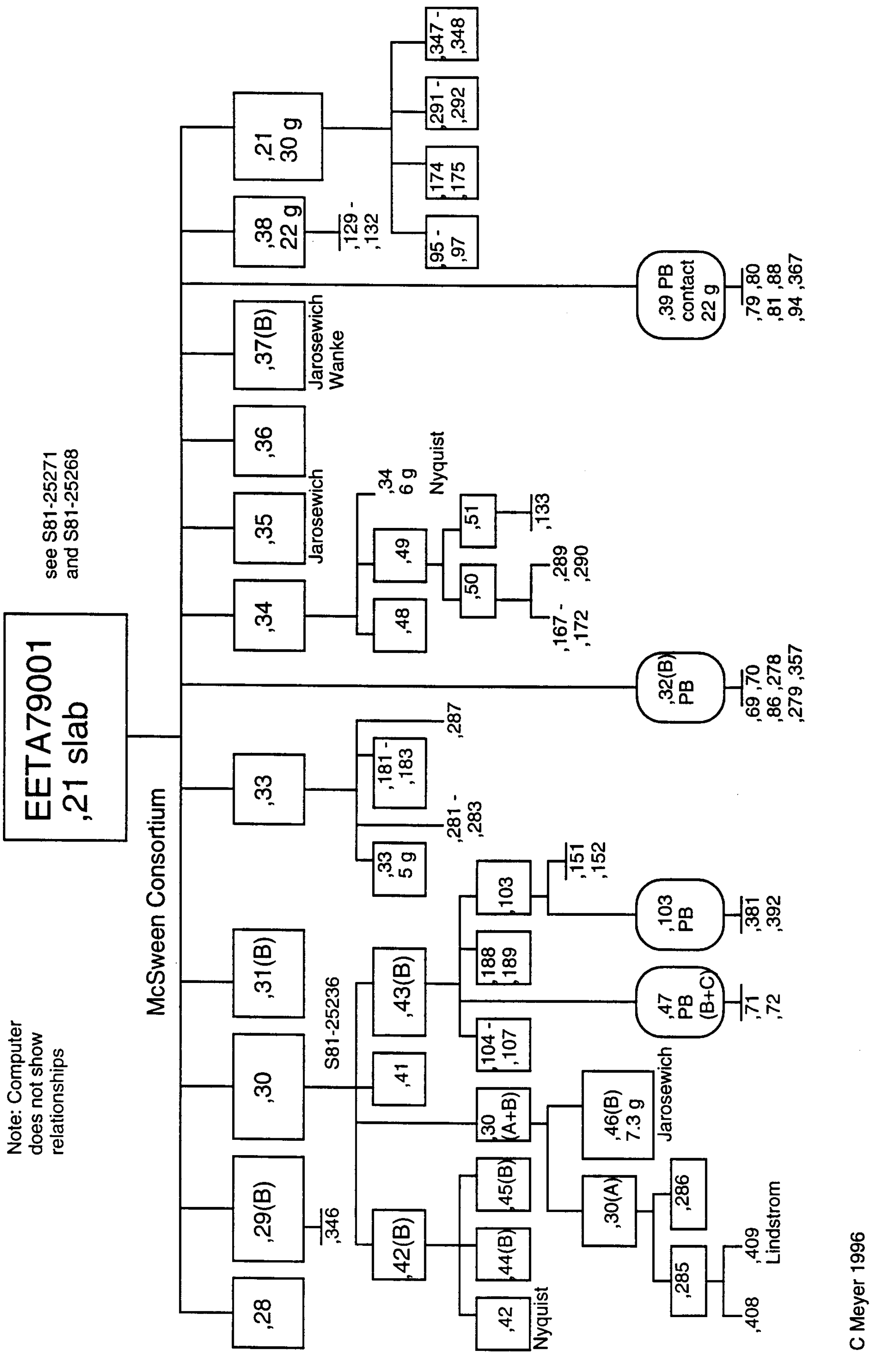

Figure IX-26. *Partial genealogy diagram of slab ,21 of EETA79001. See also figure IX-20.*

Table IX-4. EETA79001 Thin Sections (66).

Potted Butt	Thin Section	Parent
,3	,14 Treiman	,0 lith A
	,15 Mason	
	,90 MCC	
	,284 Shaw	
	,442 Yanai	
	,443 Mikouchi	
	,448 McKenzie	
	,449 Walker	
,9	,16 Jagoutz	,0 lith B
	,17 Mason	
	,178 Huguenin	
	,318 Crozaz	
	,444 Yanai	
,11	,18 Treiman	,0 lith C
	,19 MCC	
	,20 MCC	
,26	,67 Reid	,22 lith A
	,68 Treiman	
	,230 ,231 ,232 Ed Thin	
,32	,69 MCC	,21 lith B
	,70 Reid	
	,86 Papanastassiou	
	,278 Jagoutz	
	,279 Lipschutz	
	,357 Delaney	
	,445 Mikouchi	
,39	,79 McFadden	,21 contact
	,80 Rutherford	
	,81 Reid	
	,88 Lost	
	,94 Lambert	
	,367 Treiman	
,47	,71 Lipschutz	,43 lith B + C
	,72 Reid	
,51	,266 ,267 ,268	,21 Ed Thin
	,269 ,270 ,271	
	,317 Crozaz	
,53	,73 McFadden	,2 lith C
	,74 Reid	
	,380 Hofmann	
,56	,75 Rutherford	,2
	,76 Reid	
	,87 Barsukov	
	,177 Huguenin	
	,228 Ed TS	
	,353 Treiman	
,62	,77 MCC	,2 lith C
	,78 Reid	
,103	,381 Hofmann	,43 lith B
	,392 Papanastassiou	
	,446 McKenzie	
	,447 Walker	
,146	,153 MCC	,61
,330	,382 Hofmann	,312 druze
,403	,436 Lindstrom	,312
,411	,437 Lindstrom	,216
,413	,438 Lindstrom	,216
,421	,439 Lindstrom	,216
,423	,440 Lindstrom	,216
,425	,441 Lindstrom	,216

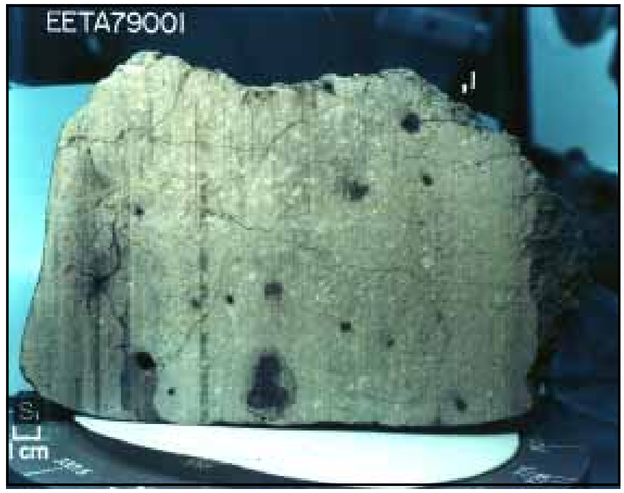

Figure IX-27. *Sawn face of EETA 79001 after first sawcut (NASA #S80-37631).*

Figure IX-28. *Sawn face of EETA 79001 after first sawcut (NASA #S80-37632).*

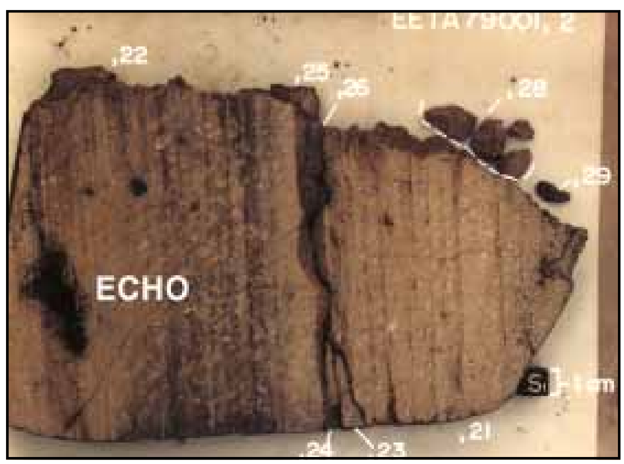

Figure IX-29. *Slab face of EETA 79001 with chips (NASA #S80-25272).*

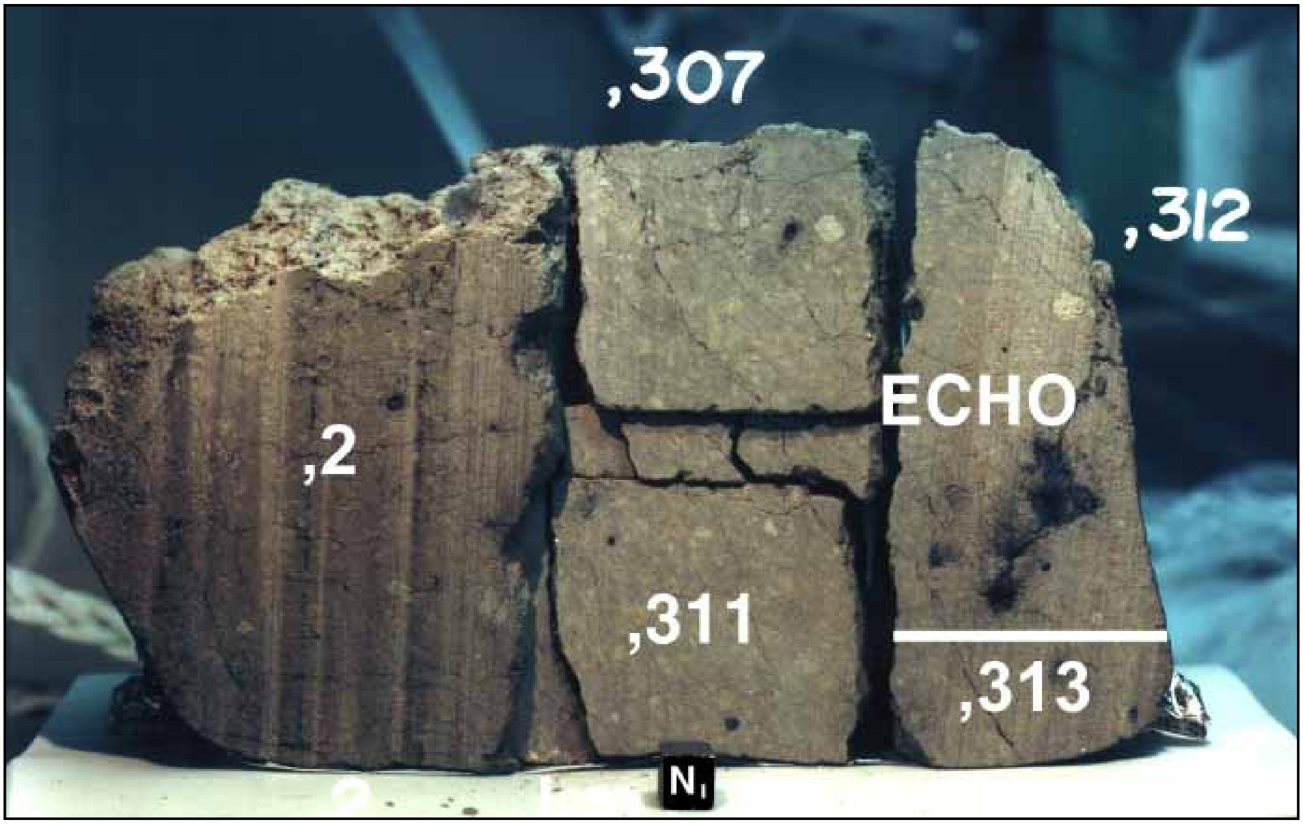

Figure IX-30. *Group photo of EETA79001,2 after second cut showing additional cuts made in 1990 (NASA #S90-34035).*

Figure IX-31. *Sawn face of EETA 79001 showing thin glass veins (NASA #S90-34040).*

Figure IX-32. *Sawn face of EETA 79001 showing different lithologies (NASA #S90-34042).*

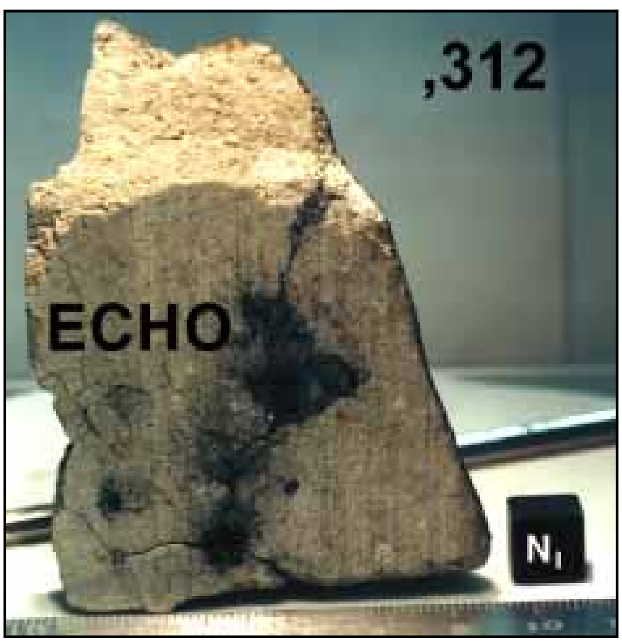

Figure IX-33. *Close-up of glass inclusion (ECHO) on EETA 79001,312 (NASA #93-33193).*

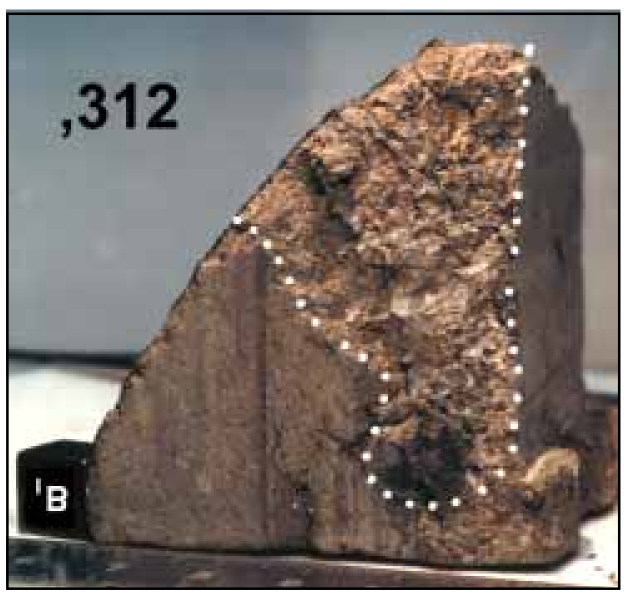

Figure IX-34. *Close-up area of "druse" obtained for search for amino acids (,363) along fracture in ,312. (NASA #93-33190).*